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MATHEMATICAL MODELING FOR CROP INSURANCE BASED ON SOCIAL SECURITY PRINCIPLE IN COMPUTING THE CROP PREMIUM

ADISAK PONGPULLPONSAK, SUKUMAN SARIKAVANIJ and THIRADET JIARASUKSAKUN

Department of Mathematics
Faculty of Science
King Mongkut's University of Technology Thonburi
126 Pracha-Uthid Rd., Bangmod, Thung-Khru
Bangkok 10140, Thailand

Abstract

This work aims to study and construct a mathematical model for a crop insurance based on the social security principle in computing the crop premium and comparing to the government's relief. The scope of the research is to study the premiums of several loss ratios depending on different severity rates and damage rates of crop after flood. The result shows that the more loss ratio, the less is the premium. For the damage rates ranging from 0.1 to 0.8, the estimating crop insurance premiums based on social security principle will be close to the amount of the government's relief fund. On the other hand, if the damage rate is higher than 0.9, the crop insurance premiums based on social security principle will be much more than the amount of the government's relief fund.

Crop insurance is a type of insurance made for agriculturists whose crops are damaged by some nature disasters such as storm, hale and flood. In Thailand, there was a crop insurance testing during years 1978-1980. However, it was unsuccessful

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due to several factors such as too few numbers of insured agriculturists, too small insured areas, lack of agriculturists' understanding of crop insurance, and too little amount of premiums to cover all compensations after disasters. Nowadays Thai government helps agriculturists who suffer from flood causing their crop damage by paying them an average rate. Thus there is damage estimation before government's compensation and crop insurance for all agriculturists. In other countries, there have been crop insurances for a while. For example, USA started to have crop insurance in 1938 by founding Federal Crop Insurance Corporation -FCIC. US government owned all of FCIC's stocks. US crop insurance covered the crop damage from disasters and it was voluntary. Thus only a few US agriculturists paid for crop insurance. After that there was a legislation to force every agriculturist under central US government in having basic crop insurance by paying only a little fee. Moreover, FCIC offered the optional several crop insurance plans in which central US government and agriculturists shared the premium cost. In Canada, there was a law about crop insurance for natural disasters since 1939. The central government covered most of the premium fee. Later there was a relief fund to help agriculturists in case of high damage and a campaign for special agriculturists' saving accounts so that a portion of their income was saved for emergency. Loajirachunkul and Chaisilaparungreung [2] had a research on appropriate crop insurances, costs and plans in Thailand. They suggested that crop insurance in Thailand should begin with the one that covers a capital production. The crop insurance plans could be categorized by types of crops, types of disasters, capital production costs and agricultural areas. The damage of the crop during cultivated season, in the beginning, includes the crop capital production from natural disasters. The rates of premiums are determined by agricultural data in the cultivated season from 1988/89 to 1997/98. This information may help the government to provide sufficient budget in order to prevent and resolve the flood problem. The victims of the disasters are adequately compensated. There are many countries which have already been using the above strategy such as United States of America, Canada, India and Australia. Thus the mathematical model for premium calculation should be studied in order to construct a mathematical model that can be used in the estimation of the damaged crops and the measured relief plan for agriculturists conducted by the government.

Principle Idea of the Damaged Crop Model

From 1989 to 2006, the floods in Thailand could be analyzed that, on the average, there were 11 flooding occurred each year. The floods covered mostly the

areas in 64 provinces. It caused human lives about 152 people each year. Approximately, in a year, 9,458,057 Rai* was destroyed by the flood. The highest numbers of flooded provinces occurred in 1994 and 1996. There were 74 provinces flooded. In 1989 and 2006, there were 602 people and 446 people died, respectively, from the flood. The year that has the most people injured was 1989, there were 5,495 people injured. In 2001, the most damage caused to the farm by the flood where 29,133,765 Rai* were destroyed. The details are shown in Table 1.

Note. "*Rai" is a Thai measurement for area which is 2.5 Rai $= 1$ Acre.

Table 1. The damage caused from the flood to areas and lives of agriculturists (classified by year)

Year	Flood frequencies	Number of flooded areas				Dead people	Wounded people	Damaged area (Rai)
		Provinces	Cities	Districts	Villages			
1992	10	66	531	2,217	12,101	16	-	14,298,000
1993	9	42	441	1,664	8,960	47	254	16,024,259
1994	11	74	620	2,119	9,170	46	12	14,000,259
1995	8	73	650	2,160	11,175	442	11	3,792,364
1996	10	74	610	2,411	12,615	158	21	21,014,456
1997	7	64	486	1,860	10,610	98	427	12,269,013
1998	12	65	522	2,215	12,117	8	3	466,074
1999	9	69	472	1,450	6,219	53	30	3,038,167
2000	12	62	653	2,325	13,029	120	-	10,340,584
2001	14	60	628	2,760	10,996	244	68	29,133,765
2002	5	72	636	3,820	18,510	216	-	10,435,115
2003	17	66	349	1,331	5,281	44	10	1,595,557
2004	12	59	337	1,856	9,964	26	3	3,298,733
2005	12	63	541	2,342	10,326	75	100	1,701,450
2006	6	58	520	3,432	22,771	446	1,462	6,560,541
Mean	11	64	522	2,185	11,363	152	529	9,458,057

Source. Office of Public Hazard Relief, Department of Disaster Prevention and Mitigation Ministry of Interior.

Miller et al. [3] did a research on an appropriate premium rate estimation for agriculturists in Georgia. The model is mentioned such that the damage and insurance of net premium rate equal to a fraction of the damage-estimate value and the maximum damage value,

$$R = E(L)/Y_g. \tag{1}$$

Babcock and Hart [1] studied APH plan and insurance, and premium reduction for agriculturists. For example, the change of income average is equal to the difference between the average compensation value (I) and the premium of producer value (PP) that is insured for 75% and 65%. The research indicates that 75% of the premium in APH program for corn, soybean, and wheat is equal to 65% of the premium multiplied by 1.538. The equation is then,

$$\Delta PP = p \times Y \times \text{rate}\,65 \times (1.538 \times 0.75 \times (1 - psub\,75) - 0.65 \times (1 - psub\,65)), \tag{2}$$

where Y is the amount of product of agriculturists and p is the insured price.

The appropriate compensation should be

$$\Delta I = p \times Y \times (0.75 \times \text{rate}\,75 - 0.65 \times \text{rate}\,65). \tag{3}$$

Pongpullponsak et al. [4] did a research on the format and model in insurance mathematics to propose to the Office of Workmen's Compensation Fund in Social Security Office (Ministry of Labor). The research shows that the main issues of consideration of the premium and compensation funds are the specific factors that the Office of Workmen's Compensation Fund uses as a determination. The main factors are the chance of risk and value of benefit compensation. The chance of risk is the first factor that determines how much the main premium will be collected from employers by the Office of Workmen's Compensation Fund. This depends on the risk of the business company. At the same time, the results of the risk of the beneficiary will determine the value of the beneficial compensation. The amount of money that has to be paid for beneficiary is determined from the severity of the danger. The rate of premium will be considered by the value of beneficial compensation depending on the severity of the damage. The estimation of net premium without the payment of managing (the premium equals compensated money) is as the following:

$$\text{Adjusted premium} = \text{wage} * \text{adjusted premium rate}, \tag{4}$$

$$\text{Total premium} = \text{premium rate} * \text{rewarding rate} + \text{adjusted premium rate}, \tag{5}$$

Rewarding rate will be considered from loss ratio:

Loss ratio can be calculated by

Loss ratio = Compensated money/Main net premium,

Y_{t-1} Compensated money in year $t-1$

X_t Total cumulative premium in year t

L_t Loss ratio in year t

$$L_t = \frac{Y_{t-1}}{X_t}. \tag{6}$$

Mathematical Model used for Crop Premium Estimation: A Case Study of the Premium Equals Crop Compensation

To construct a mathematical model used for crop insurance by social security method to calculate the crop damage premium insurance, it will have to consider the limitation and hypothesis that all households must really be flooded and be beyond the insurance. This is impossible to receive the information from the households which are not reported. It suggests that the non-agricultural households will not have any problems during the insurance period. Thus the payment for the insurance will be zero. The consideration will be determined by the statistic records in order to calculate the premium of crop damage as the following:

1. Premium = average income per Rai $*$ premium rate,
2. Total premium = premium $*$ total agricultures and animal farming areas

   = total income $*$ premium rate,
3. Loss ratio could be computed by

   Loss ratio = Compensated money/Total premium,

   Y_{t-1} Compensated money in year $t-1$

   X_t Total cumulative premium in year t

   L_t Loss ratio in year t

$$L_t = \frac{Y_{t-1}}{X_t}. \tag{7}$$

This model is made on the hypothesis that all the agriculturists join and gladly pay the premium for the crop insurance fund of the government. This case is similar to the social security method. From the formula above, there are two variables that can be specified. They are premium rate and loss ratio. In order to calculate the result, we need to know total income value, cultivated area or total domestic animals, average income, and previous compensated money from the questionnaires. The results are shown in Tables 2 and 3.

Table 2. Total income, cultivated area, average income and compensated money for each plant

Type of plant	Total income	Cultivated area (Rai)	Average income per farm	Government's relief
Horticulture	14,291,801,576.01	2,110,211.81	6,772.69	651,397,210.10
Farm	12,534,148,771.73	1,942,289.73	6,453.28	143,697,209.95
Rice	74,733,161,723.26	16,279,596.85	4,613.94	390,984,883.67
Miscellaneous	61,243,667,669.13	13,533,435.44	4,525.36	409,261,335.75

Table 3. Total income, number of domestic animals, average income and compensated money for each animal

Type of animal	Total income	Total number of animals	Average income per unit	Total compensated money
Chicken and duck (unit)	1,544,815,750.05	10,484,977.00	147.34	180,220,841.15
Pig (unit)	1,292,850,000.00	694,568.88	1,861.37	5,328,823.50
Fish (pool)	1,072,280,428.04	112,799.16	9,506.10	210,609,937.30

The mathematics model for specifying the premium rate via social security method will depend on loss ratio and compensated money that agriculturists used to obtain in the previous year. If the government wishes that all agriculturists pay their own premium insurance by themselves, the government can set the loss ratio arbitrarily. If the loss ratio equals to 1, that means to return all the money to agriculturists at the same amount of the net premium which will be all collected to

the fund (without any reduction of other expenses). This method will save the government's money from the compensation to agriculturists' loss after the flood. On the other hand, if the loss rate is more than 1, that means the compensation payment to agriculturists is more than the net premium. If the government takes the responsibility for the crop insurance, they will have to pay for the surplus money.

Table 4. Premium rates and total premiums classified by types of plants and animals when the loss ratio is fixed at 0.80

Type of plant	**Loss ratio**	**Premium rate (%)**	**Premium per Rai (Baht)**	**Area per household (Rai)**	**Premium per household**
Horticulture	0.80	5.70	385.86	5.035425	1,942.97
Farm plant	0.80	19.00	1,226.12	4.634725	5,682.75
Rice	0.80	0.65	30.17	38.650225	1,166.22
Miscellaneous	0.80	0.84	37.80	35.917975	1,357.73
Type of animal	**Loss ratio**	**Premium rate (%)**	**Premium per unit (Baht)**	**Unit number per household**	**Premium per household**
Chicken and duck	0.80	14.58	21.49	127	2,728.67
Pig	0.80	0.52	9.59	30	287.70
Fish	0.80	24.55	2,333.90	2	4,667.81

From the calculation shown in Table 4, the premium rate, and the compensated money of each plant and animal are different at the same loss ratio. However, the more the loss ratio, the less is the premium per household. This is because if the agriculturists have higher loss ratio, their income will be less. Hence they pay less premium insurance for the fund. At the same time, if agriculturists have low loss ratio, their income will be high and they will have to pay more for the insurance premium. This is because the development of this model will use income of the agriculturists as a basis in collecting the premium. The details are in Table 5. In Figure 1, when compared at any loss ratio, the premium per farm of the horticulture has the highest value. The next are the farm plants and various plants, respectively. The lowest value of all is the rice farm as shown in Table 5 and Figure 1.

Table 5. Premium rates and total premiums of plants with different loss ratios

Type of plant	Loss ratio	Premium rate (%)	Total premium (Baht)
Horticulture	0.60	7.60	2,590.63
	0.80	5.70	1,942.97
	1.00	4.56	1,554.38
	1.50	3.04	1,036.25
	2.00	2.28	777.19
Farm plant	0.60	1.91	571.49
	0.80	1.43	428.62
	1.00	1.15	342.89
	1.50	0.76	228.60
	2.00	0.57	171.45
Rice	0.60	0.87	1,554.96
	0.80	0.65	1,166.22
	1.00	0.52	932.98
	1.50	0.35	621.98
	2.00	0.26	466.49
Miscellaneous	0.60	1.11	1,810.31
	0.80	0.95	1,357.73
	1.00	0.67	1,086.19
	1.50	0.51	724.12
	2.00	0.38	543.09

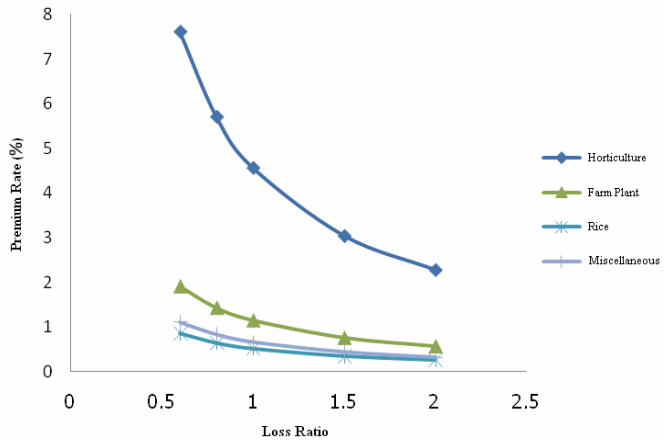

Figure 1. Premium rates per farm of each plant at different loss ratios.

Table 6. Premium rates and total premiums of animals with different loss ratios

Type of animal	Loss ratio	Premium rate (%)	Premium per household (Baht)
Chicken and duck (unit)	0.60	19.44	3,638.23
	0.80	14.58	2,728.67
	1.00	11.67	2,182.94
	1.50	7.78	1,455.29
	2.00	5.83	1,091.47
Pig (unit)	0.60	0.69	383.61
	0.80	0.52	287.70
	1.00	0.41	230.16
	1.50	0.27	153.44
	2.00	0.21	115.08
Fish (pool)	0.60	32.74	6,223.74
	0.80	24.55	4,667.81
	1.00	19.64	3,734.25
	1.50	13.09	2,489.50
	2.00	9.82	1,867.12

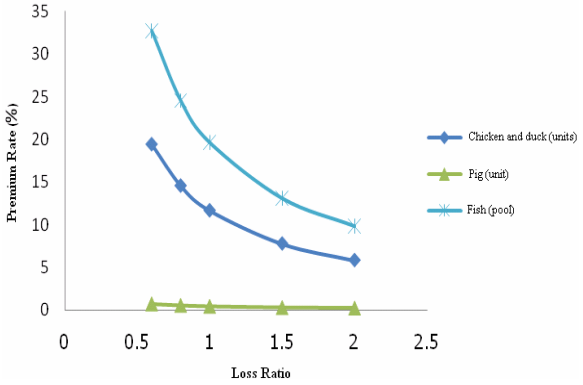

Figure 2. Premium rates per unit or pool of each animal at different loss ratios.

If the loss ratio increases, the premium rate and amount of premium decrease. The high loss ratio means collecting less in the net premium while the amount of compensated money of the previous year is constant. If the government sees that the amount of money in responsibility of the agriculturists is too high for the premium payment, the government may help them pay partly at different levels of the loss. However, this model can be used to calculate the loss ratio if there is a given rate of premium in advance. That is to say, if the government does not care about the loss ratio more than the money that agriculturists have to take the responsibility, the method in Tables 7 and 8 and Figures 3 and 4 could be used.

Table 7. Loss ratio and premium when premium rates of the plants are given

Type of plant	Premium rate (%)	Premium per household (Baht)	Loss ratio
Horticulture	0.2	68.21	22.79
	0.4	136.41	11.39
	0.6	204.62	7.60
	0.8	272.83	5.70
	1	341.03	4.56
Farm	0.2	59.82	5.73
	0.4	119.64	2.87
	0.6	179.46	1.91
	0.8	239.27	1.43
	1	299.09	1.15
Rice	0.2	356.66	2.62
	0.4	713.32	1.31
	0.6	1,069.98	0.87
	0.8	1,426.64	0.65
	1	1,783.30	0.52
Miscellaneous	0.2	325.08	3.34
	0.4	650.17	1.67
	0.6	975.25	1.11
	0.8	1,300.33	0.84
	1	1,625.42	0.76

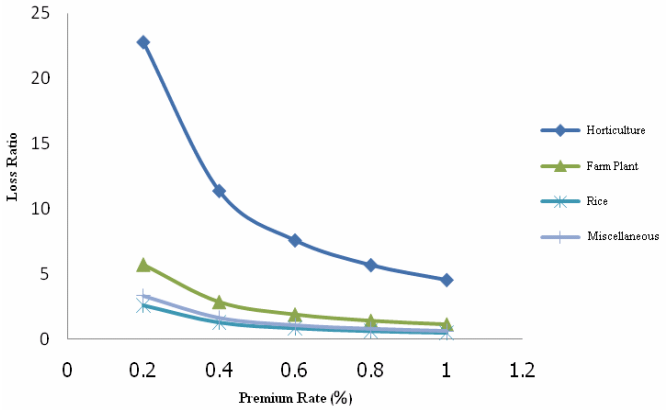

Figure 3. Loss ratio of each plant at different premium rates.

Table 8. Loss ratios and premiums of animals at different premium rates

Type of animal	Premium rate (%)	Premium per household (Baht)	Loss ratio
Chicken and duck (unit)	0.2	37.42	58.33
	0.4	74.85	29.17
	0.6	112.27	19.44
	0.8	149.69	14.58
	1	187.12	11.67
Pig (unit)	0.2	111.68	2.06
	0.4	223.36	1.03
	0.6	335.05	0.69
	0.8	446.73	0.52
	1	558.41	0.41
Fish (pool)	0.2	38.02	98.21
	0.4	76.05	49.10
	0.6	114.07	32.74
	0.8	152.10	24.55
	1	190.12	19.64

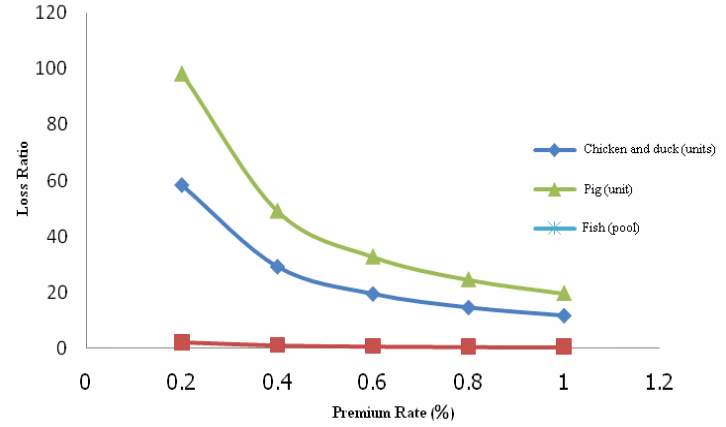

Figure 4. Loss ratio of each animal at different premium rates.

Comparison of the Total Crop Premium Insurance, Premium Rate, via the Social Security Method and the Total Government's Relief

The model indicates that the more the loss ratio, the less is the premium rate under the criterion of the average sorrow and happiness. Now let us consider the model under the condition of severity rate at level 500,000 (the calculation of severity rate is the quotient of the total value of damage and the total damaged

households in the central part of Thailand). The damage rates vary at different levels from 0.1 to 0.9, where the damage rate is the total number of damaged households divided by total number of households in the central part of Thailand, the result is shown in Table 9 and Figure 5. For the damage rate ranging from 0.1 to 0.8, the total crop premiums collected from agriculturists (Baht/household/year) based on social security principle will be close to the amount of the government's relief fund. On the other hand, if the damage rate is higher than 0.9, the total crop premiums collected from agriculturists (Baht/household/year) based on social security principle will be much more than the amount of the government's relief fund.

Table 9. Results calculated from the model of the crop insurance by using the social security method to find the premium insurance of the damaged crop

Severity rate (*Y*)	**Damage rate (*X*)**	**Premium based on social security (Baht/ household)**	**Government's relief (Baht/ household)**	**Total premium based on social security (Baht/household/ year)**	**Total government's relief fund (Baht/household/ year)**
500,000	0.1	146.37	63.09	736,019,642.2	317,247,244.8
	0.2	164.67	126.18	828,040,954.3	634,494,489.7
	0.3	188.19	189.27	946,310,968.5	951,741,734.5
	0.4	219.56	252.36	1,104,054,606	1,268,988,979
	0.5	263.47	315.44	1,324,855,470	1,586,185,939
	0.6	329.34	378.53	1,656,081,909	1,903,433,184
	0.7	439.12	441.62	2,208,109,211	2,220,680,429
	0.8	658.67	504.71	3,312,113,532	2,537,927,674
	0.9	1317.34	567.8	6,624,227,065	2,855,174,919

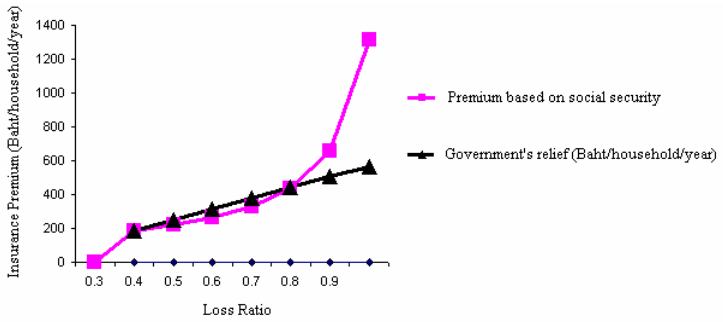

Figure 5. Comparison of the results from the model calculated crop insurance premium via social security principle and the total government's relief fund (Baht/household/year).

Conclusion

In conclusion, the model developed by Pongpullponsak et al. [4] to find appropriate premium rates in any establishment for collecting the premiums only from employers to cover employee's parts. Hence the developed model gives a close result to the government's relief plan. If we consider that the result from the calculation is a part of the fund from the government and collect partly from agriculturists which is only 50% of the government's relief, then save it in the fund (can be called as the agriculturists' relief fund after flood), it will alleviate many more suffering agriculturists. Also from the study of social security principle model, the loss ratio is equal to the quotient of the compensated money and the net premium. If we calculate along with the cultivated area, the agriculturists will have to pay for the premiums in range of 4.3725 - 39.3525 Baht/Rai a year. In average, each household has 33 Rai for cultivating.

Suggestion

The developed model is very close to the government's relief. So this model could be used as a model for yearly premium. The estimation may be used to forecast the severity rate (Y) and the damaged rate (X) in advance so as to estimate the premium for saving some fund. The money that collected from all agriculturists in Thailand which may increase to 50% of the estimated premium from the government should be enough for the damage during that time.

The study of the social security insurance principle indicates that the loss ratio is the quotient of the compensated money and the net premium. If we calculate by considering the cultivated area, the result shows that each household has only 33 Rai. Thus agriculturists in each household must pay the insurance 144.29 - 1,298.63 Baht/month. That is 1.083% - 9.745% of monthly income. This is not a lot of money but an agriculturist may not be able to pay it off.

There has not been a model to estimate the severity rate (Y) and the damage rate (X) in advance. In the next study, the model that can estimate the severity rate (Y) and the damage rate (X) in advance should be created. Also find the premium of the suitable agriculturist household in order to join the government's relief from the estimation of this study.

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